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Article

Mapping the risk of forest fires in the watershed of Oued Bougous (Northeast of Algeria)

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Abstract. The objective of this study is to map the risk of forest fires at the scale of the Oued Bougous watershed in the extreme northeast of Algeria using remote sensing and GIS. We used a fire risk mapping model which is based on a number of parameters, namely: the type of vegetation, the slope, the exposure, the proximity of roads and agglomerations. The result obtained revealed that 79.88% of the study area represents a very high to high risk. This risk is essentially linked to highly flammable vegetation, steep slopes, southern exposure, a dense road network and a significant human presence within the forest. The established fire risk index map is a real decision-making tool, but it remains insufficient, because there are other anthropogenic factors that trigger forest fires that are not taken into account by the adopted model, such as the agricultural practice especially the harvest campaign and the border situation of the watershed with Tunisia.

Keywords: Fire, GIS and Remote Sensing, Watershed, Oued Bougous, Algeria.

Résumé. L'objectif de cette étude est de cartographier le risque de feux de forêt à l'échelle du bassin versant de l'Oued Bougous à l'extrême nord-est de l'Algérie à l'aide de la télédétection et du SIG. Nous avons utilisé un modèle de cartographie du risque d'incendie qui repose sur un certain nombre de paramètres, à savoir : le type de végétation, la pente, l'exposition, la proximité des routes et des agglomérations. Le résultat obtenu a révélé que 79,88% de la zone d'étude représente un risque très élevé à élevé. Ce risque est essentiellement lié à une végétation hautement inflammable, des pentes abruptes, une exposition sud, un réseau routier dense et une présence humaine importante au sein de la forêt. La carte d'indices de risque d'incendie établie est un véritable outil d'aide à la décision, mais elle reste insuffisante, car il existe d'autres facteurs anthropiques déclencheurs de feux de forêt qui ne sont pas pris en compte par le modèle adopté, comme la pratique agricole notamment la campagne de récolte et la situation frontalière du bassin versant avec la Tunisie.

Mots-clés: Feu, SIG et Télédétection, Bassin versant, Oued Bougous, Algérie

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Introduction

In the Mediterranean region, the forest fire is an old and recurrent phenomenon that has largely oriented the evolution and dynamics of forests and natural areas (Lazreg, 2015). Unfortunately, the forests in this region are gradually being reduced by destructive fires. Each year, more than 50,000 fires burn 1.5% of the total Mediterranean forests (Siachalou et al., 2009; Khader et al., 2009; Falehet al., 2012; Ouahiba, 2014). Algeria is one of the Mediterranean countries where the problem of forest fires is little known by the scientific community, which pulses with acuteness its destructive impact. The areas burned remain relatively modest compared to other countries in the Mediterranean basin (Ouahiba & Christine, 2013; Benderradji et al., 2004). Each year, more than 20,000 hectares of forests are destroyed by fires in Algeria (Belhadj-Aissa et al., 2003). At the scale of the Oued Bougous watershed, and like in the northern Algerian region, the forest heritage is suffering the effects of degradation, because of its floristic composition in highly combustible species, of the Mediterranean climate (hot and dry in summer) which favours the outbreak of fires and of the human activity which exerts quite strong pressure on the forest heritage. Fire is the natural threat and chronic phenomenon that weighs heavily on the forests of this watershed. Repeated forest fires are major obstacles to the regeneration of vegetation and contribute to the emergence of water erosion (Khallef et al., 2021; Khallef et al., 2018). Only in the Municipality of Bougous, the conservation of the forests of El Taref confirms that each year more than 80 hectares of forests and natural species are ravaged by forest fires. Despite the state's efforts for sustainable forest management, intending to protect biodiversity and the environment and to fight against forest fires, the risk is still present. Conventional prevention by traditional means remains insufficient, while today remote sensing and GIS are the most used tools in the prevention and management of disasters, in particular forest fires. The purpose of this study is to map the risk of fire at the scale of the Oued Bougous watershed through a model adapted to the Mediterranean region, using remote sensing and geographic information systems.

1. Materials and methods

1.1. Study area

The Oued Bougous watershed is entirely included in the El Kala National Park, with an area of 14,744 ha. It is located in the northeast of Algeria, delimited by the following geographical coordinates: between 36°48'47.30''N and 36°36'56.69''N latitude and between 8°30'23.89''E and 8°24'11.33''E longitude (Figure 1). It is delimited to the east by the Algerian-Tunisian border, to the north by the watersheds of Lake Oubeira and Tonga, to the west by the end of the alluvial plain of Annaba and to the south of the Medjerda Mountains.

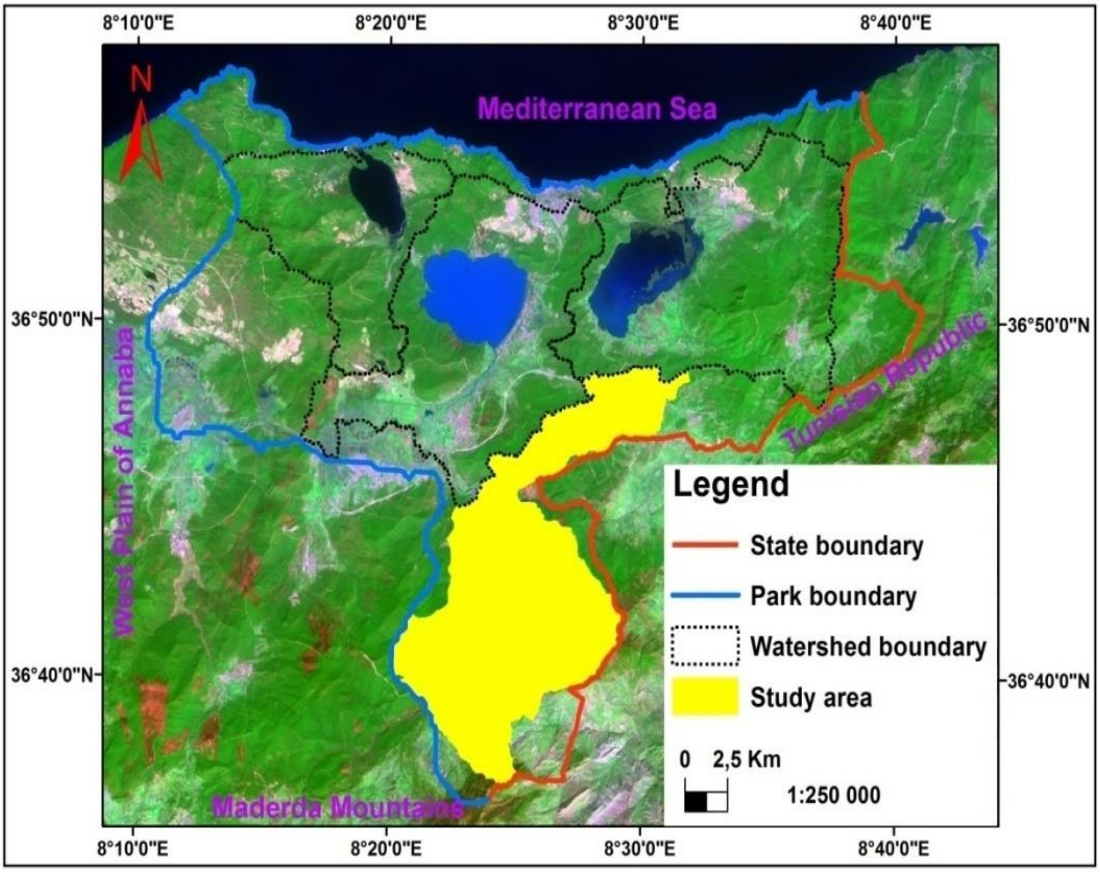

Figure 1. Location of study area

The watershed of Oued Bougous releases a mosaic of topographic shapes and colours. The first topographical form that stands out is the one that occupies the water; it is the domain of the dams, and geographically it constitutes an intermediate space between the hills and the mountain environment.

The climate is of the sub humid Mediterranean type with a rainy period from October to April and a dry period from May to September, with rainfall amounts varying between 710 and 910 mm/year. The average annual temperature is around 18°C (Khallef et al., 2018). The hottest months are July and August when the average temperature hovers around 25°C. The coldest months are December and January with average temperatures around 12°C (Khallef et al., 2021). The vegetation cover in this watershed is very diverse and takes different forms, globally distributed in forests, maquis, rangelands, and agricultural land (Khallef et al., 2021) (Figure 2). This particular feature of the watershed has experienced an alarming regression in recent years caused by several factors, the most important of which are of anthropogenic origin (fires).

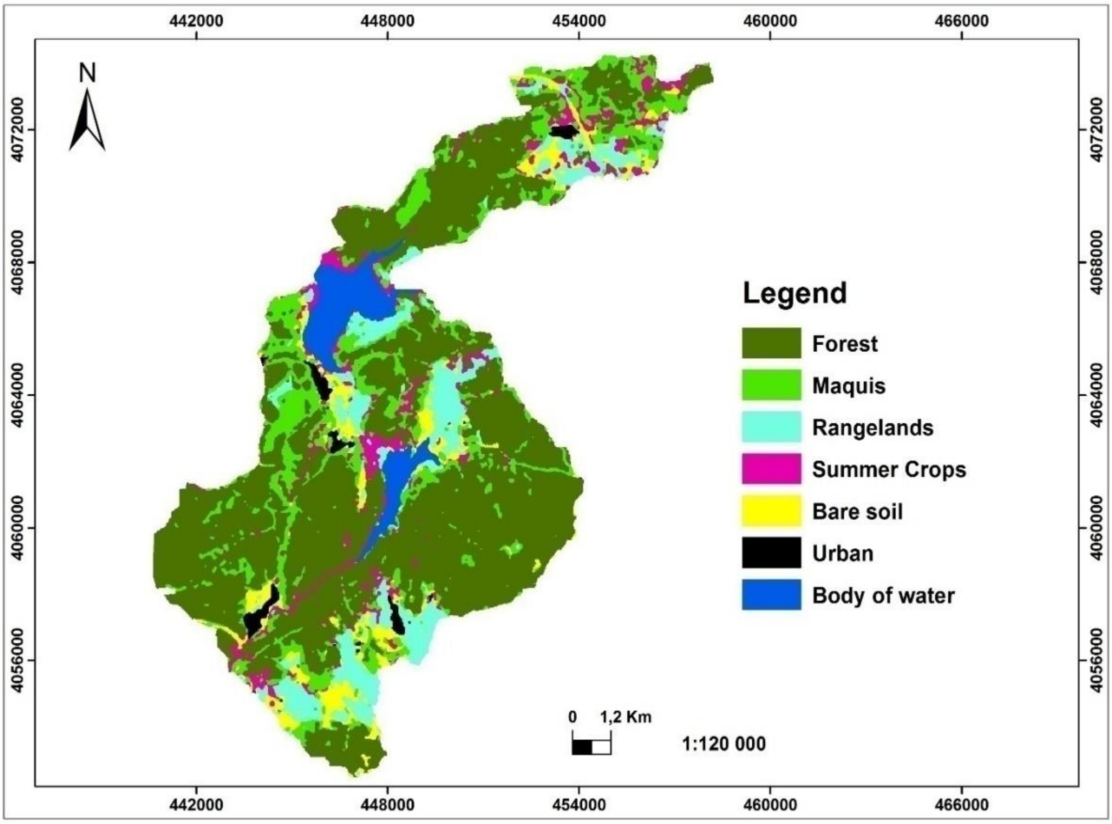

Figure 2. Land cover of the Oued Bougous watershed

1.2. Methodology

The development of an operational fire risk assessment system requires at least three main stages, namely: the generation of the required input variables, the proposal of the means to integrate them into synthetic indices and the dissemination of the indices to the forest managers. Fire danger indices have many potential uses, the most important being to reduce the negative effects of fires by introducing risk reduction strategies (Chuvieco et al., 2014). The fire risk assessment method at the scale of the Oued Bougous watershed consists of calculating the various factors involved in the forest fire risk index. The model set up by the Turks and tested in Algeria on the Akfadou-Est forest, Bejaia (Mazi, 2015), the Fenouane Ain El Hdjar forest, Saida (Hachemi, 2014) was retained to map the risk of fires in the watershed of Oued Bougous. For this study, data collected from an online global database was combined with administrative documents, statistics and field missions were organized in November 2021 to take GPS points in burned areas. Table 1 summarizes the remote sensing data used in this research.

Table 1. Remote sensing data used

Sensor	Acquisition date	Resolution (m)
Sentinel 2	07/12/2021	10
Landsat 8 OLI	22/06/2021	30
Landsat 8 OLI	13/11/2021	30
Aster GDEM	30/11/2013	30
Google Earth	09/04/2021	1

The pre-processing and the image processing were carried out under ENVI 5.1 software, while the analysis, the combination of all the data and the application of the model were carried out with the ArcGis 10.2.2 software. The working resolution is 30 m and the projection system applied to all our data is Transverse Mercator zone 32N.

1.3. Model selected

We chose the Turkish model for two main reasons: its adaptability to Mediterranean regions and its simplicity of execution. This model involves the five main factors for the evaluation of the risk of forest fire, namely: the slope, the exposure, the type of vegetation, the distance from the roads and the distance from the settlements (Erten et al., 2004; Siachalou et al., 2009). The model is based on the following formula:

$$RC = 7 * V_T + 5 * (S + A) + 3 * (D_R + D_S) \qquad (1)$$

where

RC: Forest fire risk index

$\boldsymbol{V_T}$**:** Vegetation index relating to the degree of flammability, which is related to the humidity of the vegetation (Erten et al., 2004). Drought is one of the most critical parameters in fire risk, as it increases the flammability of any type of dry vegetation.

S: Slope index. According to Rothermel (1991), the slope is one of the parameters which influence the behaviour of the fire. The slope modifies the relative inclination of the flame front in relation to the ground. However, a steep slope may contribute either to accelerating or slowing down the spread of a fire depending on whether or not the orientation coincides with the direction of spread (Belhadj-Aissa et al., 2003).

A: Aspect index. South-facing slopes have direct sunlight in the northern hemisphere, resulting in drier soil and more susceptible to inflammation (Faleh et al.,2012).

$\boldsymbol{D_R}$**:** Index of distance from roads. Forest regions located near roads are more exposed to fire because roads and paths are access routes to go to the forest which causes fires (Jaiswal et al.,2002).

$\boldsymbol{D_S}$**:** Index of distance from settlements. Studies show that the risk of fire is higher in areas where there are settlements in or around the forest (Jaiswal et al., 2002; Belhadj-Aissa et al., 2003; Erten et al.,2004). Human presence inside or near a forest can trigger fires due to different activities: agriculture, grazing, logging, construction, extraction, etc. (Carrega, 2008).

The different stages of the adopted methodology are represented by the following summarized flowchart (Figure 3).

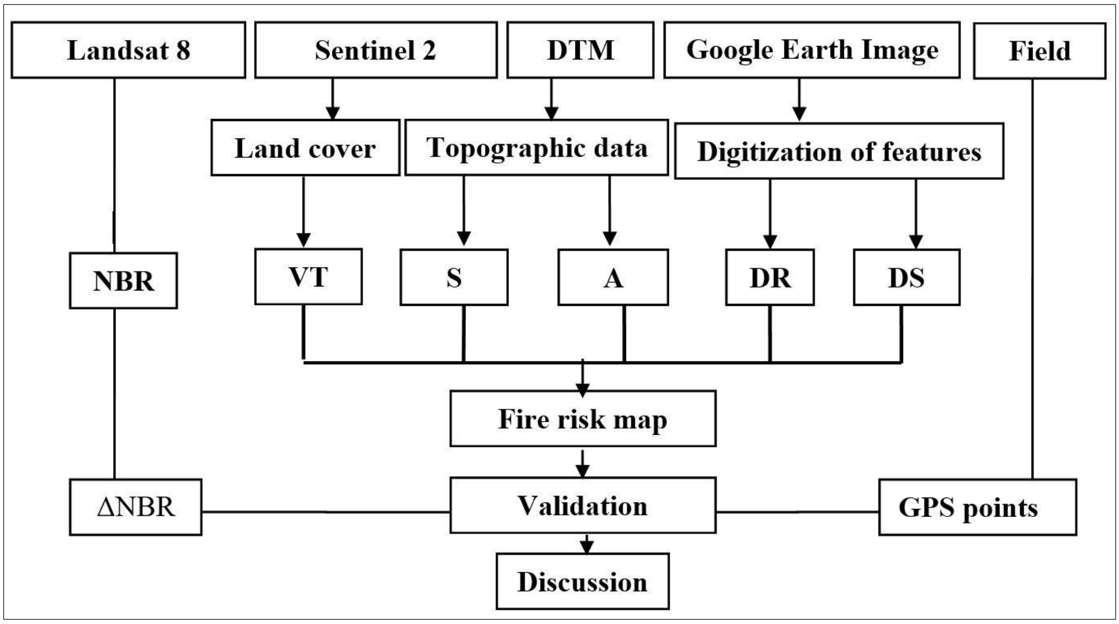

Figure 3. Flow chart of the forest fire risk index calculation procedure

2. Results

Based on the flowchart of the procedure for calculating the forest fire risk index (Figure 3), we applied the model adapted to the various factors.

2.1. Vegetation Index (VI)

The vegetation index in our case study is calculated from the interpretation of the land cover map: Sentinel 2 image classified selected for the year 2021. The type of vegetation in the area under study is classified according to its degree of flammability linked to its hydric state (water content) according to the model set up by CEMACREF in 1989. CEMAGREF (National Centre for Agricultural Machinery, Rural Engineering, Water and Forests) defines flammability (according to its technical guide for Mediterranean foresters) as a parameter that qualifies the ease with which the fine elements of a given plant species take lights. The measurement of the ignition time that elapses between the presentation of a plant sample to the heat source and the appearance of the first flames makes it possible to classify the different plant species and their forms in order of flammability (Delabraze, 1974). The flammability of the vegetation would lead to the inevitable return of fire

(Clément,2008). The flammability of a plant is its ability to burn, it is the combination of four components, namely: its ability to ignite, its ability to continue to burn, its ability to release energy and to burn quickly and its ability to burn out (Clément, 2008). For the Oued Bougous watershed, forest species are classified according to the standards of the adopted model (Table 2) following the model established by CMAGREF which classifies Mediterranean forest species according to the flammability index (Table 3).

Table 2. Classification of Mediterranean forest species according to the flammability index (CMAGREF: Guide for Mediterranean foresters)

Flammability	Factor	Forest species
Very low	1	Body of water
Low	2	Bare soil
		Urban
Medium	3	Juniper Oxycedar
		Irrigated crops
High	4	Rangelands
		Cistus
		Olive growing
		Eucalyptus
		Juniper of Phoenicia
Very high	5	Cork Oak
		Holm Oak
		Aleppo pine
		Maquis

Table 3. Classification of the type of vegetation into risk classes

Variable	Type of Vegetation	Factor	Risk	Area (ha)	Percentage (%)
VT	Body of water	1	Very low	734	4 .98
	Bare soil, Urban	2	Low	1038	7.04
	Summer crops	3	Medium	847	5.74
	Rangelands	4	High	3416	23.17
	Forest, reforestation, maquis	5	Very high	8709	59.07
Total				14744	100.00

On the basis of Table 3, we can see that 82.24 % of the study area presents a high to very high risk, i.e. stake 12,125 hectares of cork oak, reforestation, maquis and herbaceous plants. The average risk affects 5.74 % of the area or 847 hectares. Lowest to very low risk classes represent 12.02 %, i.e. an area of 1,772 hectares of zero vegetation cover (Figure 4).

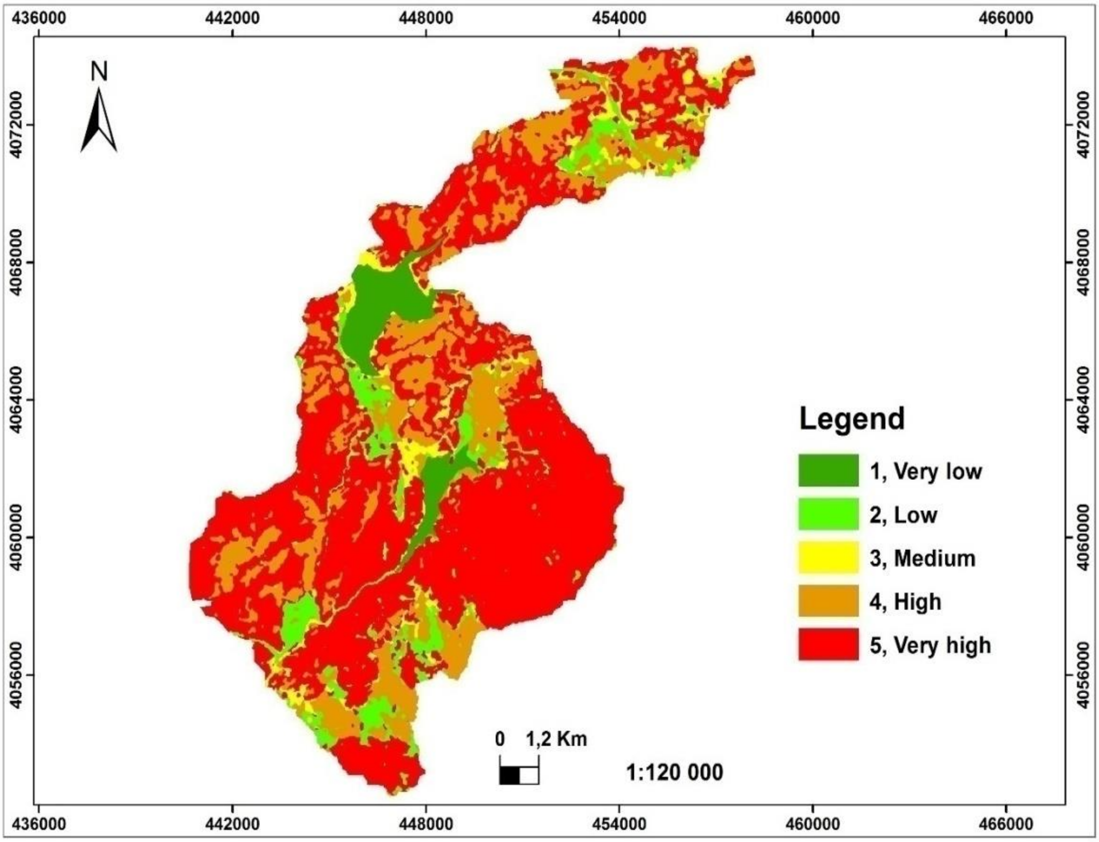

Figure 4. Map of the vegetation index

2.2. Slope index (S)

The factor that influences the behaviour of forest fires is the topographical nature of the terrain or the slope. This is the single most important factor of terrain when it comes to wildfires, as fires generally climb faster on slopes and the steeper the slope, the faster the fire spreads. The fires move in the direction of the surrounding winds, which generally blow upwards. Additionally, the fire is able to preheat the fuel at the top of the hill as the smoke and heat rise in that direction. So once the fire reaches the top of the hill, you have to struggle and then come back down because it is unable to preheat the fuel for the slopes as well as the climb. Fires that move slower uphill are an exception to the rule, but this can happen (Sallaoua, 2021). The slope index map is extracted from the DTM (Figure 5). Five slope classes were selected based on their incidence, their frequency of occurrence and their spatial distribution and area to draw up the slope index map (Table 4).

Table 4. Classification of the Slope index into risk classes

Variable	Classes	Factor	Risk	Area (ha)	Percentage (%)
Slope	< % 5	1	Very low	1808	12.26
	5 - 10%	2	low	2121	14.39
	10 - 25%	3	Medium	8508	57.70
	25 - 35%	4	High	1629	11.05
	> 35%	5	Very high	678	4.6
Total				14744	100.00

According to Table 4, the medium risk classes are the most represented, they occupy 57.70% more than half of the study area, i.e. 8508 hectares covering the entire part of the lower foothills. The very low to low-risk classes represent 26.65% or 3929 hectares; they are generally spread over the plains. Unlike the previous classes, higher risk class covers an area of 1629 hectares or 11.05% of the total area of the study perimeter; they cover all the hills and the high foothills. The very high risk class represents 4.60% of the total area, i.e. 678 hectares. This class is spread over mountain ranges (Djbel Ghorra and Oum Ali).

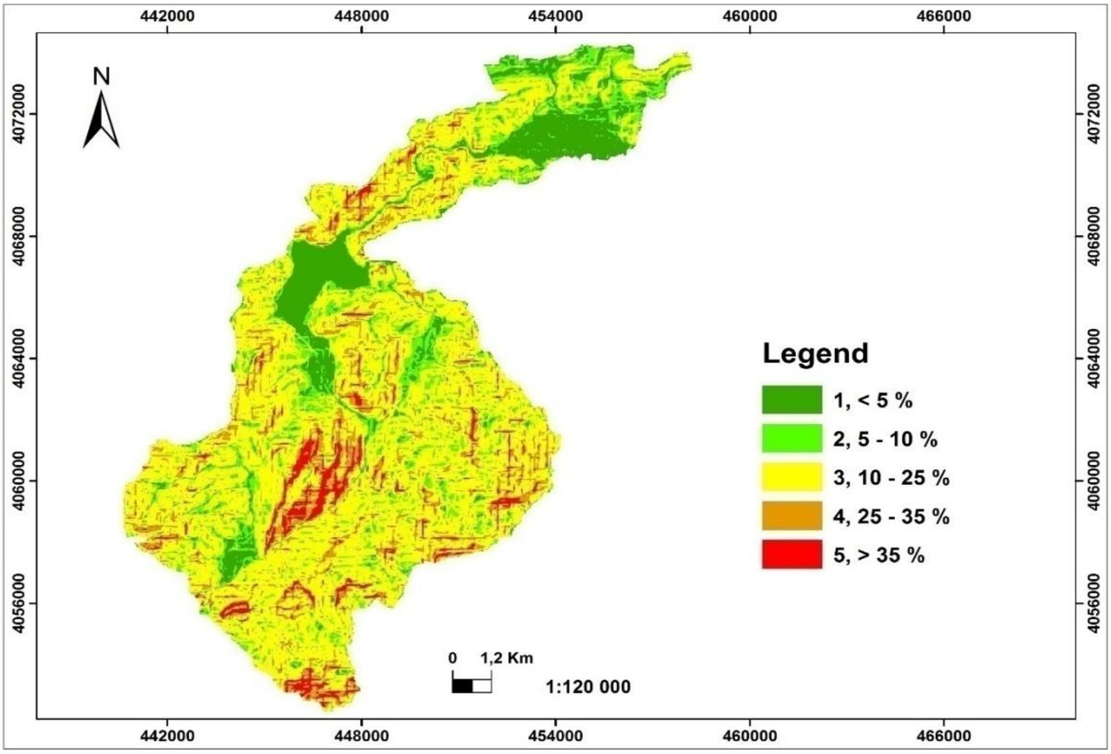

Figure 5. Map of the slope index

2.3. Aspect index (A)

The aspect reflects the situation of the slope in relation to the sunshine. Generally, the southern slopes present the most favourable conditions for rapid ignition and the spread of flames, unlike the northern slopes which are shaded (La documentation française, 2002). In our case study, the extraction of the aspect index map from the digital terrain model (DTM) made it possible to spatialize four main risk classes determined in relation to the four cardinal points with values expressed in degrees taking north as the origin. The aspect index is calculated according to the standards of the selected model (Figure 6). The spatial analysis of this index allowed us to extract the information summarized in Table 5.

Table 5. Classification of the Aspect index into risk classes

Variable	Exposure	Factor	Risk	Area (ha)	Percentage (%)
Aspect	North	2	Low	4218	28.61
	East	3	Medium	2890	19.60
	West	4	High	5279	35.80
	South	5	Very high	2357	15.99
Total				14744	100.00

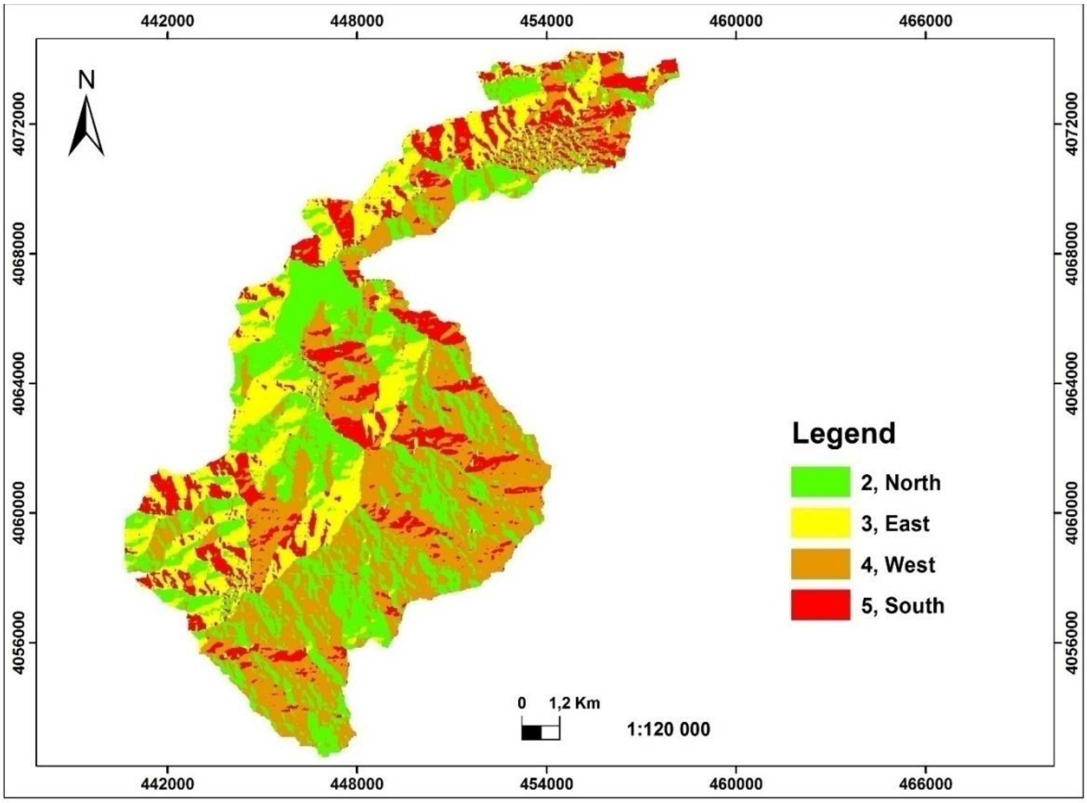

Figure 6. Map of the aspect index

According to Table 5, 51.79% of the total surface area of the watershed represents the class from high risk to very high risk, i.e. 7636 hectares with southern and western exposure. The medium risk class represents 19.60% with an area of 2890 hectares and the low-risk class represents 28.61% or 4218 hectares spread over the extent of the plain.

2.4. Distance from Roads index (DR)

Transport infrastructure (roads, paths and tracks) plays a major role in triggering forest fires. Fire outbreaks are much more frequent near these infrastructures. In the case of the Oued Bougous watershed, the transport infrastructures are digitized from the Google Earth image. The calculation of the road proximity index is carried out based on the creation of buffer zones according to the distance entered in the table above as shown in Figure 7.

Table 6. Classification of the distance from road index into risk classes

Variable	Classes	Factor	Risk	Area (ha)	Percentage (%)
Distance from road (DR)	> 400 m	1	Very low	5701	38.67
	300 - 400 m	2	low	1658	11.25
	200 - 300 m	3	Medium	2015	13.67
	100 - 200 m	4	High	2426	16.45
	< 100 m	5	Very high	2944	19.97
Total				14744	100.00

Table 6 indicates that 49.91% of the study area presents a high to very high risk for which the proximity distance is greater than 300 m, while the medium risk class represents 13.67% for a proximity distance between 200 to 300m. However, the low to very low risk class less than or equal to 200 m of proximity represents 36.42% of the total area of the study perimeter.

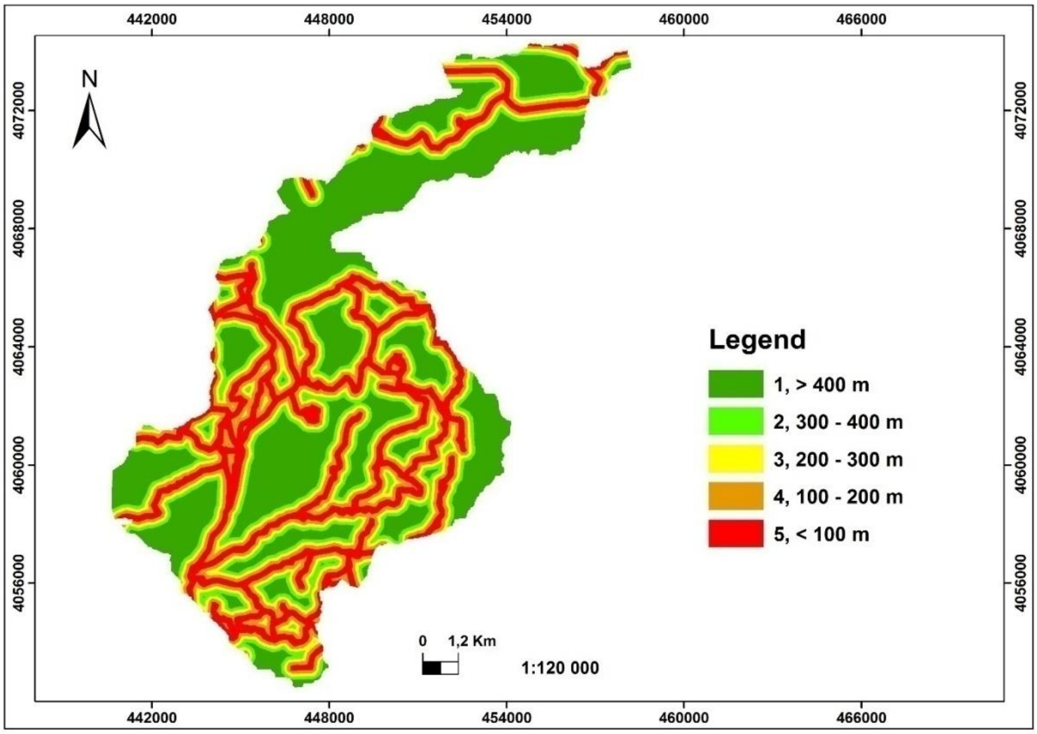

Figure 7. Map of the distance from roads index

2.5. Distance from settlements index (DS)

The expansion of dwellings on the edge of forests and the dispersion of constructions in rural areas, multiply the potential points of accidental fire starting. At the scale of the Oued Bougous watershed, the proximity index of settlements is assimilated by buffer surfaces around urban areas and dwellings located within the forest. Figure 8 illustrates the space involved, according to the degree of fire risk. The operation of calculating the buffer zones around the settlements made it possible to extract the following information from the allocation table (Table 7).

Table 7. Classification of the distance from Settlements index into risk classes

Variable	Classes	Factor	Risk	Area (ha)	Percentage (%)
Distance from Settlements (DS)	> 3000 m	2	low	578	3.92
	2000 - 3000 m	3	Medium	1613	10.94
	1000 - 2000 m	4	High	4949	33.57
	< 1000 m	5	Very high	7604	51.57
Total				14744	100.00

The spatial distribution of the index of proximity to Settlements shows that the last two classes of high to very high risk are the most dominant classes, i.e. 85.14% of the total of the study area and this is explained by the dispersion of dwellings near depth less than 2000 m. The medium to low-risk classes occupy 14.86% of the total area of the study perimeter.

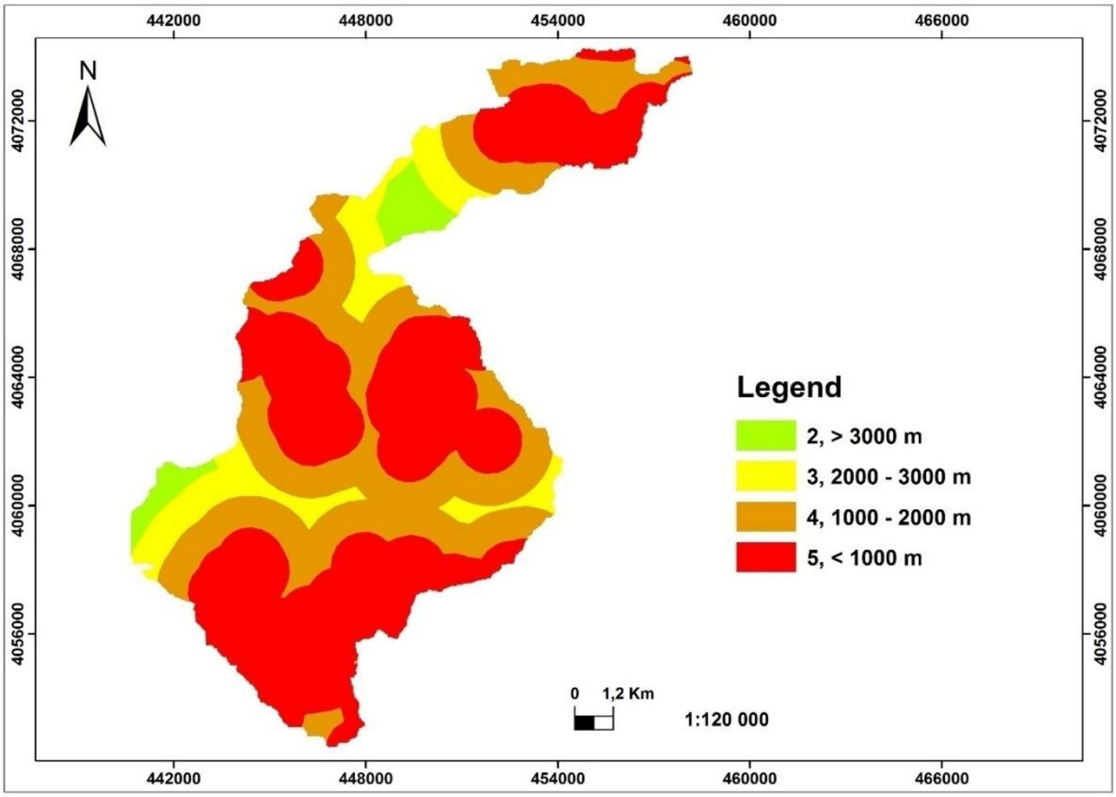

Figure 8. Map of the distance from Settlements index

2.6. The forest fire risk index (RC)

Fire risk mapping allows us to determine potential fire starting and outbreak areas using natural and anthropogenic influence parameters. The fire risk index is calculated after the intersection (Crossing) of the different layers produced. This involves applying the formula of the model adapted to the various indices: vegetation type, slope, aspect, distance from the roads and distance from settlements in vector format (Figure 9).

Table 8 shows that the study area is dominated by areas of high to very high fire risk, i.e. 79.88% (RC varies from 60 to > 90) for an area of 11,778 hectares of the total area, distributed throughout the territory of the watershed. Areas of medium fire risk (RC varied from 45 to 60) occupy 2079 hectares and represent 14.10% of the total areas and are evenly distributed throughout the study area. Low to very low fire risk classes (RC < 60) occupy 887 hectares or 6.01% of the total area nether is also located throughout the entire in the study area.

Table 8. Classification of the forest fire risk index (RC)

Index	Classes	Factor	Risk	Area (ha)	Percentage (%)
RC	< 45	1	Very low	413	2.80
	45 - 60	2	low	474	3.21
	60 - 75	3	Medium	2079	14.10
	75 - 90	4	High	7649	51.88
	> 90	5	Very high	4129	28.00
	Total			14744	100.00

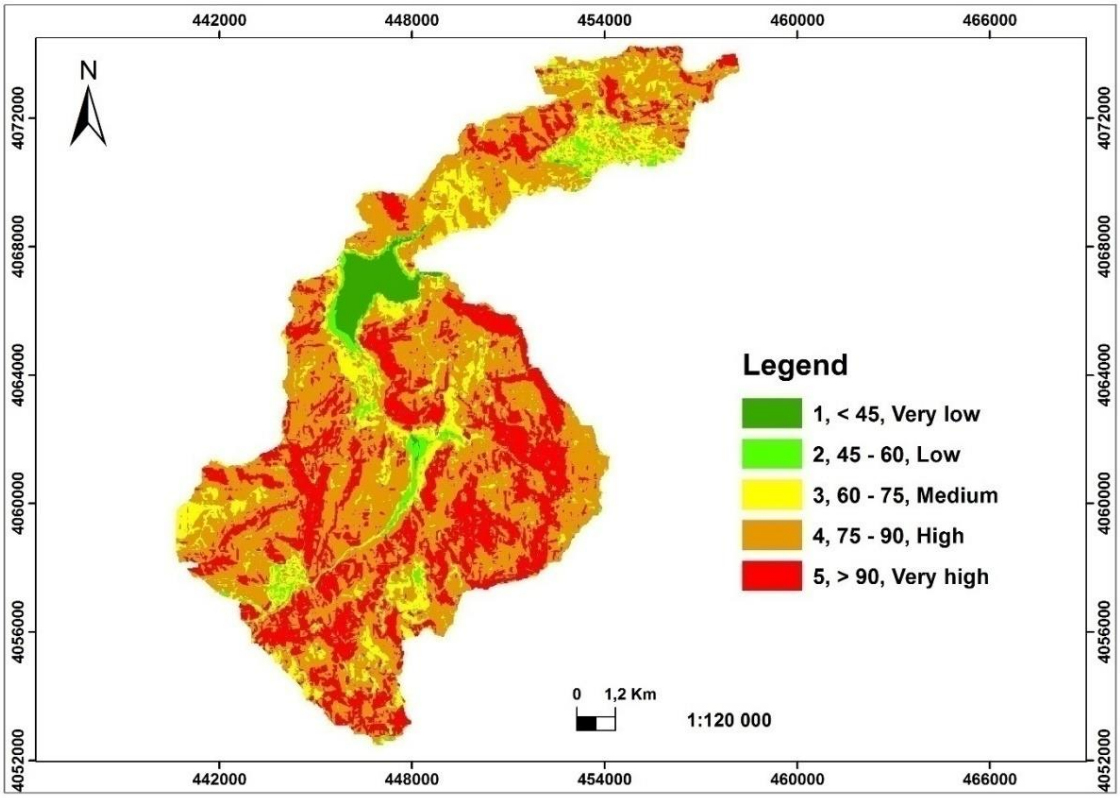

Figure 9. Map of the forest fire index (RC)

3. Validation

The validation of the model is made by two different methods, the first consist of the field survey using a navigation GPS to take GPS points of the areas burned just in 2021, the second is based on the exploitation of the remote sensing data to calculate the differential normalized burn ratio (dNBR) to extract burnt areas. Figure 10 shows the result of this superimposition. Among the seven fire points located in the study area, two are in very high-risk areas, four are in high-risk areas and one is in medium risk areas for a total area of 215.72 ha (Table 9).

Table 9. Points of fires in 2021 (Oued Bougous watershed)

GPS Points	Forest fire Risk (RC)				
7	Very low	Low	Medium	High	Very high
	0	0	1	4	2

The areas affected by the fire during the year of 2021 are located in the southern, central and northern part of the study area, these areas are known by strong human pressure (agricultural activities, grazing, dense road infrastructure and massive frequentation during the summer season) and a type of flammable vegetation, in particular the cork oak in the southern part of the watershed.

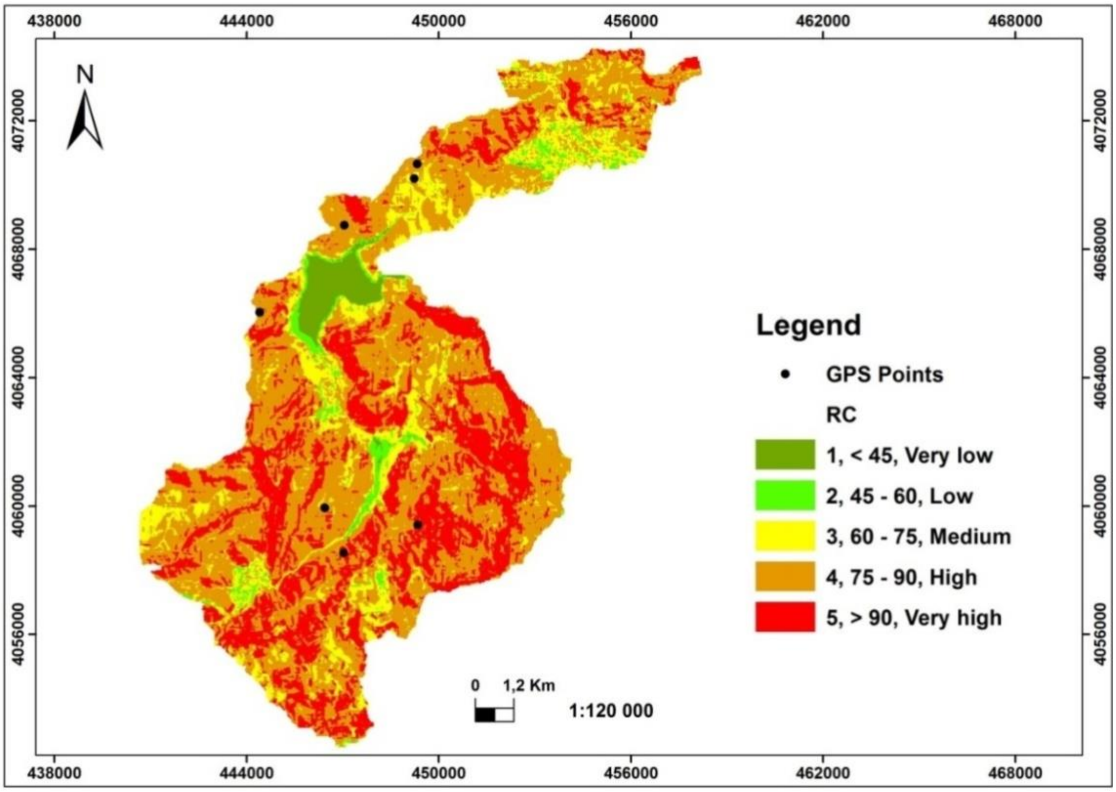

Figure 10. Validation of the model using the field survey

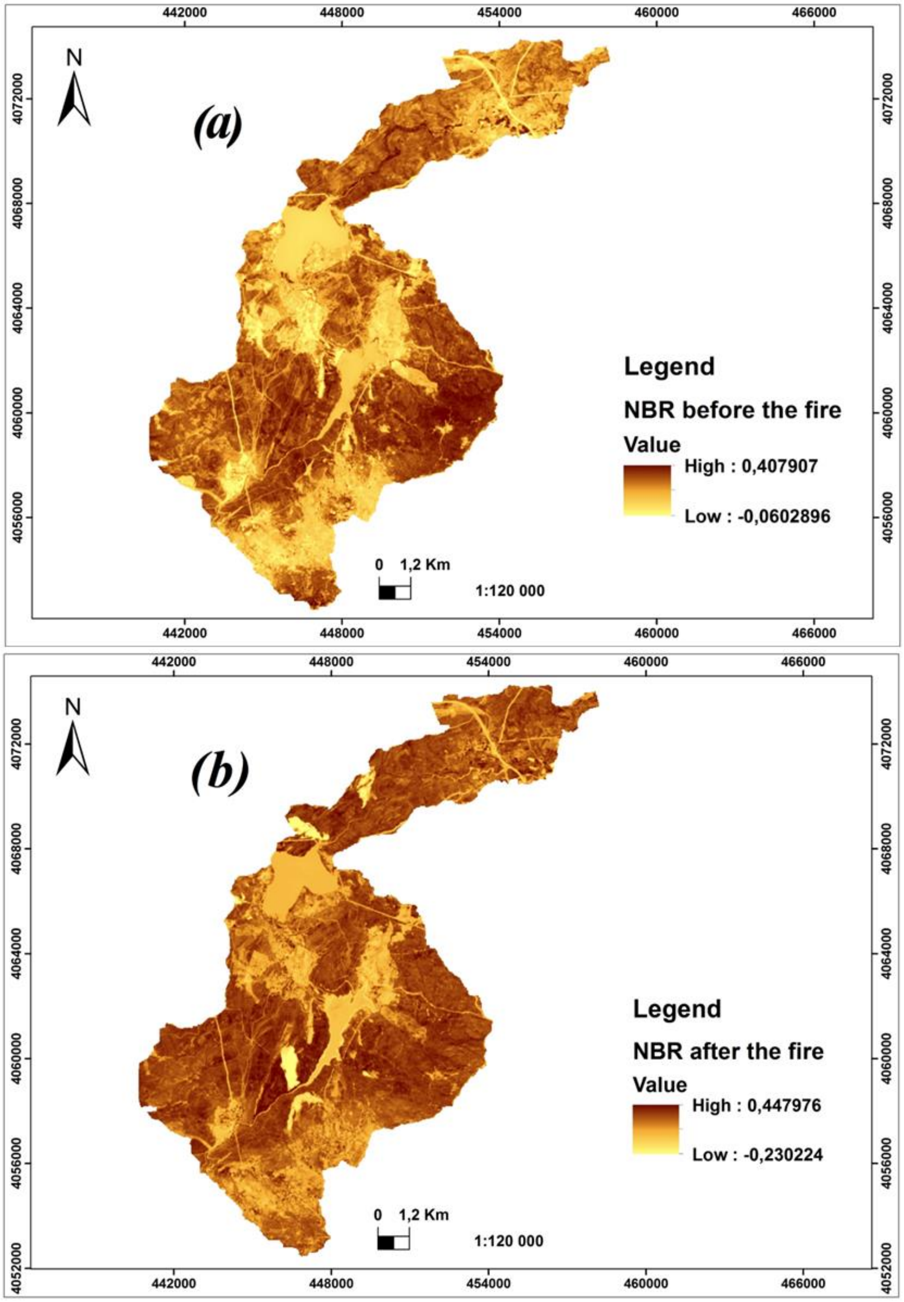

Figure 11. Normalized burn ratio (NBR) (a) before the fire and (b) after the fire

The Normalized Burn Ratio (NBR) allows the areas that have burned to be highlighted and also to revalue the severity of a burn using satellite images (Escuin et al, 2007). For a given area the NBR is calculated by the following equation:

$$NBR = (NIR - SWIR\ 2)/(NIR + SWIR\ 2) \qquad (2)$$

Where

NIR: Near Infrared (Band 5 for landsat8 OLI)
SWIR 2: Short waver infrared (B7 for Landsat8 OLI)
The NBR is calculated from an image just before the passage of the fires and a second NBR after the burn. The difference between these two indices makes it possible to clearly display the burned areas. This difference is expressed by the following formula:

$$\Delta NBR = (NBR1 - NBR2) \qquad (3)$$

Where
NBR1: normalized burn ratio calculated before the fires
NBR2: normalized burn ratio calculated after the fires
For the case of the Oued Bougous watershed, Figure 11 shows the normalized burn ration (NBR) calculated before the fire and after the fire using equation 2. The superposition of the resulting fire risk index map and the layers of burned areas extracted from the produced ΔNBR map, made it possible to evaluate the effectiveness of the adopted model. Figure 12 shows that the fires produced are located in high to very high-risk areas. This validation, which consisted of satellite images, confirms de reliability of the adopted model.

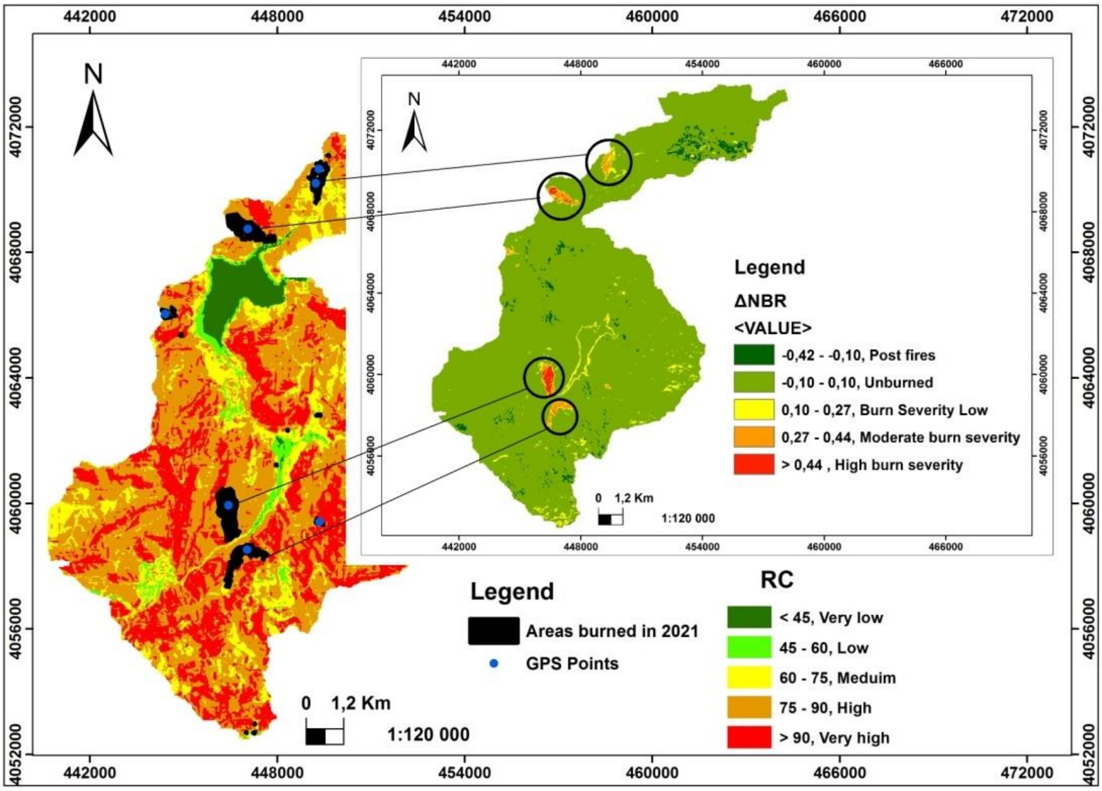

Figure 12. Validation of the model using remote sensing data

4. Discussion

The superposition of GPS points and the calculation of the differential NBR thanks to satellite images (areas burned in 2021 and map of fire risk indices) showed that the fires produced are generally located in high to very high-risk areas. This observation is corroborated by Figure 10 and Figure 11, following verification of the effectiveness of the adopted model. Indeed, the field survey in addition to the remote sensing data made it possible to identify the areas affected by forest fires in 2021 on the map of the fire risk index. This makes it possible to certify the validity of the model for the case of the study area. In addition, the production of a fire risk index map has made it possible to identify the following areas:

Zone A-high to very high-risk classes:

- Type of flammable vegetation (cork oak forests, maquis, grasses, litter and agricultural abandonment)
- Strong human presence (tourism during the summer season, agricultural activities, urbanization).
- A dense road infrastructure (national roads, Wilaya paths, communal paths, forest tracks).
- A very high slope to be raised (hills, foothills, mountains).
- A south and west exposure.

Zone B-Zones of the medium risk class, distributed throughout the territory of the catchment area. They are generally east facing with a slightly high slope in some places in the south and west, covered with vegetation moderately resistant to forest fires.

Zone C-low to very low risk classes:

- These are northern exposure areas and flat areas
- From a very low to zero slope (plains, dams).
- Vegetation resistant to forest fires (yards).
- Bare soil (ploughing, subdivisions)
- Weak sprawl.

Conclusion

The present paper proposed a map of the forest fire risk in the watershed of Oued Bougous, using remote sensing and GIS. The result obtained shows that 79.88% of the study area presents a high to very high risk. This result from the adopted model was validated using the identification of fire sites observed in the field and remote sensing data. The established fire risk index map is an effective tool for defining priorities for the installation or maintenance of infrastructure for fighting and developing areas exposed to the risk of fire. Nevertheless, this map remains insufficient, as it is necessary to return to the main causes of the outbreak of fires because related to other anthropogenic factors triggering forest fires, which are not taken into account by the model adopted such as agricultural practice, especially summer crops and the companion of harvest. Also, the watershed is located at the Algerian-Tunisian border and some fires occur on this border.

Disclosure statement

No potential conflict of interest was reported by the authors.

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